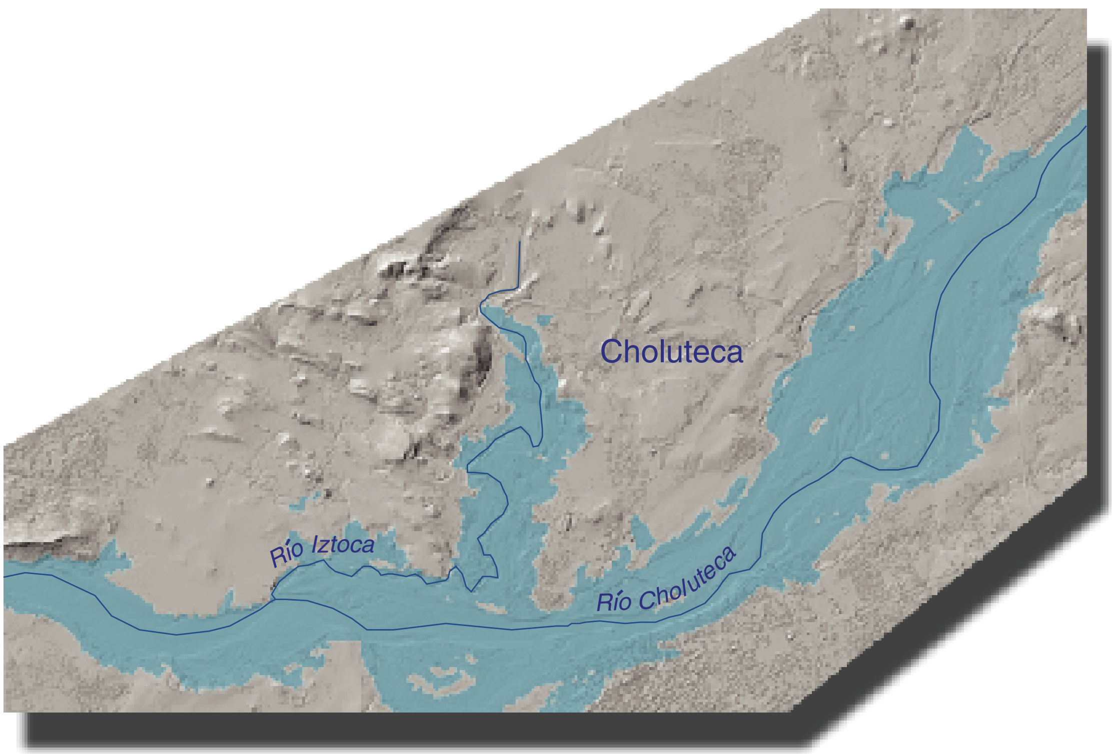
Prepared in cooperation with the U.S Agency for International Development

Fifty-Year Flood-Inundation Maps for Choluteca, Honduras

U.S. Geological Survey Open-File Report 02-250



U.S. Department of the Interior
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U.S. GEOLOGICAL SURVEY

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Tacoma, Washington
2002

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CONTENTS

FIGURES

TABLES

CONVERSION FACTORS AND VERTICAL DATUM

CONVERSION FACTORS

Multiply	By	To obtain
cubic meter per second (m^3/s)	35.31	cubic foot per second
kilometer (km)	0.6214	mile
meter (m)	3.281	foot
millimeter (mm)	0.03937	inch
square kilometer (km^2)	0.3861	square mile

VERTICAL DATUM

Elevation: In this report "elevation" refers to the height, in meters, above the ellipsoid defined by the World Geodetic System of 1984 (WGS 84).

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ABSTRACT

After the devastating floods caused by Hurricane Mitch in 1998, maps of the areas and depths of 50-year-flood inundation at 15 municipalities in Honduras were prepared as a tool for agencies involved in reconstruction and planning. This report, which is one in a series of 15, presents maps of areas in the municipality of Choluteca that would be inundated by 50-year floods on Río Choluteca and Río Iztoca. Geographic Information System (GIS) coverages of the flood inundation are available on a computer in the municipality of Choluteca as part of the Municipal GIS project and on the Internet at the Flood Hazard Mapping Web page (http://mitchnts1.cr.usgs.gov/projects/floodhazard.html). These coverages allow users to view the flood inundation in much more detail than is possible using the maps in this report.

Water-surface elevations for 50-year-floods on Río Choluteca and Río Iztoca at Choluteca were estimated using HEC-RAS, a one-dimensional, steady-flow, step-backwater computer program. The channel and floodplain cross sections used in HEC-RAS were developed from an airborne light-detection-and-ranging (LIDAR) topographic survey of the area.

The estimated 50-year-flood discharge for Río Choluteca at Choluteca is 4,620 cubic meters per second, which is the drainage-area-adjusted weighted-average of two independently estimated 50-year-flood discharges for the gaging station Río Choluteca en Puente Choluteca. One discharge, 4,913 cubic meters per second, was estimated from a frequency analysis of the 17 years of peak discharge record for the gage, and the other, 2,650 cubic meters per second, was estimated from a regression equation that relates the 50-year-flood discharge to drainage area and mean annual precipitation. The weighted-average of the two discharges at the gage is 4,530 cubic meters per second. The 50-year-flood discharge for the study area reach of Río Choluteca was estimated by multiplying the weighted discharge at the gage by the ratio of the drainage areas upstream from the two locations.

The 50-year-flood discharge for Río Iztoca, which was estimated from the regression equation, is 430 cubic meters per second.

INTRODUCTION

In late October 1998, Hurricane Mitch struck the mainland of Honduras, triggering destructive landslides, flooding, and other associated disasters that overwhelmed the country’s resources and ability to quickly rebuild itself. The hurricane produced more than 450 millimeters (mm) of rain in 24 hours in parts of Honduras and caused significant flooding along most rivers in the country. A hurricane of this intensity is a rare event, and Hurricane Mitch is listed as the most deadly hurricane in the Western Hemisphere since the “Great Hurricane” of 1780. However, other destructive hurricanes have hit Honduras in recent history. For example, Hurricane Fifi hit Honduras in September 1974, causing 8,000 deaths (Rappaport and Fernandez-Partagas, 1997).

As part of a relief effort in Central America, the U.S. Agency for International Development (USAID), with help from the U.S. Geological Survey (USGS), developed a program to aid Central America in rebuilding itself. A top priority identified by USAID was the need for reliable flood-hazard maps of Honduras to help plan the rebuilding of housing and infrastructure. The Water Resources Division of the USGS, in Washington State, in coordination with the International Water Resources Branch of the USGS, was given the task to develop flood-hazard maps for 15 municipalities in Honduras: Catacamas, Choloma, Choluteca, Comayagua, El Progreso, Juticalpa, La Ceiba, La Lima, Nacaome, Olanchito, Santa Rosa de Aguán, Siguatepeque, Sonaguera, Tegucigalpa, and Tocoa. This report presents and describes the determination of the area and depth of inundation in the municipality of Choluteca that would be caused by 50-year floods on Río Choluteca and Río Iztoca.

The 50-year flood was used as the target flood in this study because discussions with the USAID and the Honduran Public Works and Transportation Ministry indicated that it was the most common design flood used by planners and engineers working in Honduras. The 50-year flood is one that has a 2-percent chance of being equaled or exceeded in any one year and on average would be equalled or exceeded once every 50 years.

Purpose, Scope, and Methods

This report provides (1) results and summary of the hydrologic analysis to estimate the 50-year-flood discharges used as input to the hydraulic model, (2) results of the hydraulic analysis to estimate the water-surface elevations of the 50-year-flood discharges at cross sections along the stream profiles, and (3) 50-year-flood inundation maps for Río Choluteca and Río Iztoca at Choluteca showing area and depth of inundation.

The analytical methods used to estimate the 50-year-flood discharges, to calculate the water-surface elevations, and to create the flood-inundation maps are described in a companion report by Mastin (2002). Water-surface elevations along Río Choluteca and Río Iztoca were calculated using HEC-RAS, a one-dimensional, steady-flow, step-backwater computer model; and maps of the area and depths of inundation were generated from the water-surface elevations and topographic information.

The channel and floodplain cross sections used in HEC-RAS were developed from an airborne light-detection-and-ranging (LIDAR) topographic survey of Choluteca and ground surveys at four bridges. Because of the high cost of obtaining the LIDAR elevation data, the extent of mapping was limited to areas of high population density where flooding is expected to cause the worst damage. The findings in this report are based on the conditions of the river channels and floodplains on March 2-3, 2000, when the LIDAR data were collected, and March 14-15, 2000, when the bridges were surveyed.

Acknowledgments

We acknowledge USAID for funding this project; Jeff Phillips of the USGS for providing data and field support while we were in-country; Roger Bendeck, a Honduran interpreter, for being an indispensable guide, translator, and instrument man during our field trips; and representatives of the mayor’s office, who gave us important local insights into the hydrology of and historical flooding along Río Choluteca and Río Iztoca and allowed us access to the rivers during our field surveys.

DESCRIPTION OF STUDY AREA

Río Choluteca flows along the northern boundary of Choluteca, and Río Iztoca, a Río Choluteca tributary, flows through a rural area north of Río Choluteca. The study area includes the channel and floodplains of Río Choluteca from approximately 5.5 kilometers (km) upstream to 4.5 km downstream from Choluteca and Río Iztoca from its confluence with Río Choluteca to approximately 7 km upstream (figure 1).

The headwaters of Río Choluteca originate from several mountains in south-central Honduras. The Río Choluteca streambed material consists mainly of sand and gravel with an armoring of small to medium cobbles. The main channel banks and floodplains of Río Choluteca are generally covered with only sparse to moderate amounts of vegetation. The Río Iztoca streambed consists mainly of silt, sand, gravel, and a few small cobbles.

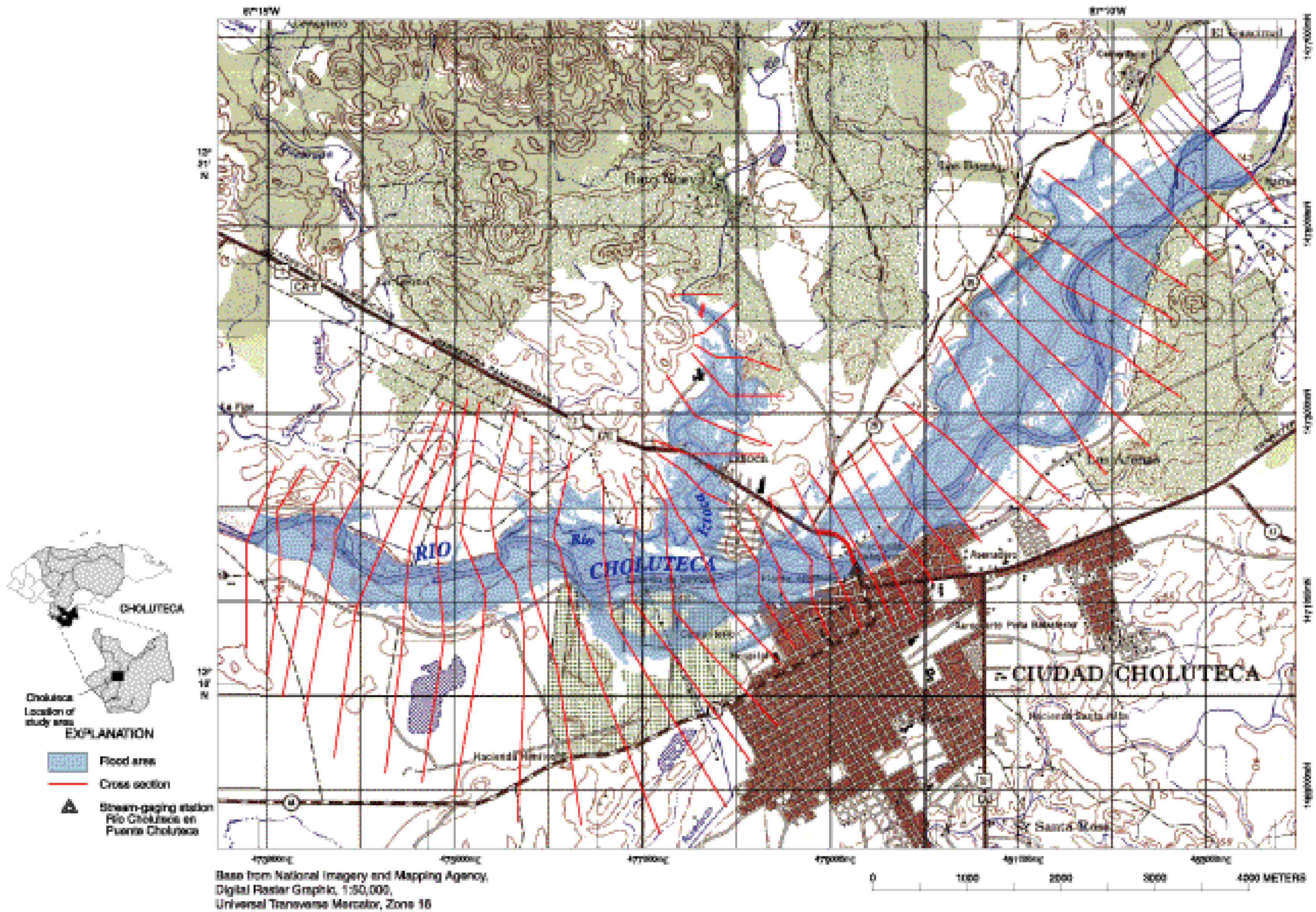

Figure 1. Location of study area and cross sections, and the area of inundation for the 50-year flood on Río Choluteca and Río Iztoca at Choluteca, Honduras.

FIFTY-YEAR FLOOD DISCHARGE

The estimated 50-year-flood discharge of Río Choluteca at Choluteca is the drainage-area adjusted weighted-average of two independently estimated 50-year-flood discharges for the gaging station Río Choluteca en Puente Choluteca; one from a frequency analysis of the annual peak-flow discharges at the gage and the other from a regression equation that relates the 50-year-flood discharge to drainage area and mean annual precipitation. The weights used in computing the average were inversely proportional to the variances of the individual estimates. Weighted averages generally provide better estimates of true flood discharges than those determined from either a flood-frequency analysis or a regression equation alone.

The Río Choluteca en Puente Choluteca stream-gaging station, which is operated by the Secretaría de Recursos Naturales y Ambiente (SERNA), the national natural resource agency in Honduras, is located at the Pan American Highway bridge crossing of Río Choluteca (figure 1) and has 17 years of annual peak flow record (table 1). The results of a frequency analysis of the annual peak discharges for the gaging station are shown in table 2 and in an exceedance-probability plot (figure 2). The 1998 annual peak discharge, which resulted from Hurricane Mitch, was estimated to be the highest peak in 65 years. Therefore, a historical adjustment was made to all the annual peak discharges to account for this (Mastin, 2002).

As shown in table 2, the 2-percent exceedance probability (50-year frequency) peak discharge calculated from the gaging station record is 4,913 cubic meters per second (m^3/s).

A regression equation (equation 1) that relates the 50-year peak flow with drainage area and mean annual precipitation was developed using data from 34 streamflow stations throughout Honduras with more than 10 years of annual peak flow record (Mastin, 2002).

Table 1. Annual peak discharges at the stream-gaging station Río Choluteca en Puente Choluteca, Honduras, for water years 1979–89, 1992–96, 1998

[**Water year**: (May 1 through April 30) is identified by the calendar year in which it begins. For example, the 1979 water year begins on May 1, 1979, and ends on April 30, 1980. **Abbreviations**: m^3/s, cubic meters per second]

Water year	Discharge (m^3/s)	Water year	Discharge (m^3/s)
1979	1,097	1988	1,912
1980	1,686	1989	1,855
1981	1,607	1992	498
1982	1,218	1993	1,470
1983	391	1994	346
1984	807	1995	1,620
1985	2,132	1996	721
1986	1,041	1998	[1]15,500
1987	457		

[1]This peak, which resulted from Hurricane Mitch, was estimated to be the highest peak in 65 years (Mastin, 2002).

Table 2. Results of frequency analysis of annual peak flow for the stream-gaging station Río Choluteca en Puente Choluteca, Honduras, for water years 1979–89, 1992–96, 1998

[**Abbreviations**: m^3/s, cubic meters per second]

Annual exceedance probability (percent)	Average recurrence interval (years)	Peak flow: Estimated value (m^3/s)	Peak flow: 95-percent confidence limits, Lower (m^3/s)	Peak flow: 95-percent confidence limits, Upper (m^3/s)
99.5	1.005	237	118	358
99	1.01	266	139	394
95	1.05	375	221	526
90	1.1	457	287	624
80	1.2	590	399	785
50	2	1,009	756	1,335
20	5	1,839	1,386	2,703
10	10	2,584	1,879	4,194
4	25	3,791	2,600	7,002
2	50	4,913	3,219	9,961
1	100	6,250	3,915	13,860
0.5	200	7,843	4,700	18,960
.2	500	10,410	5,895	28,080

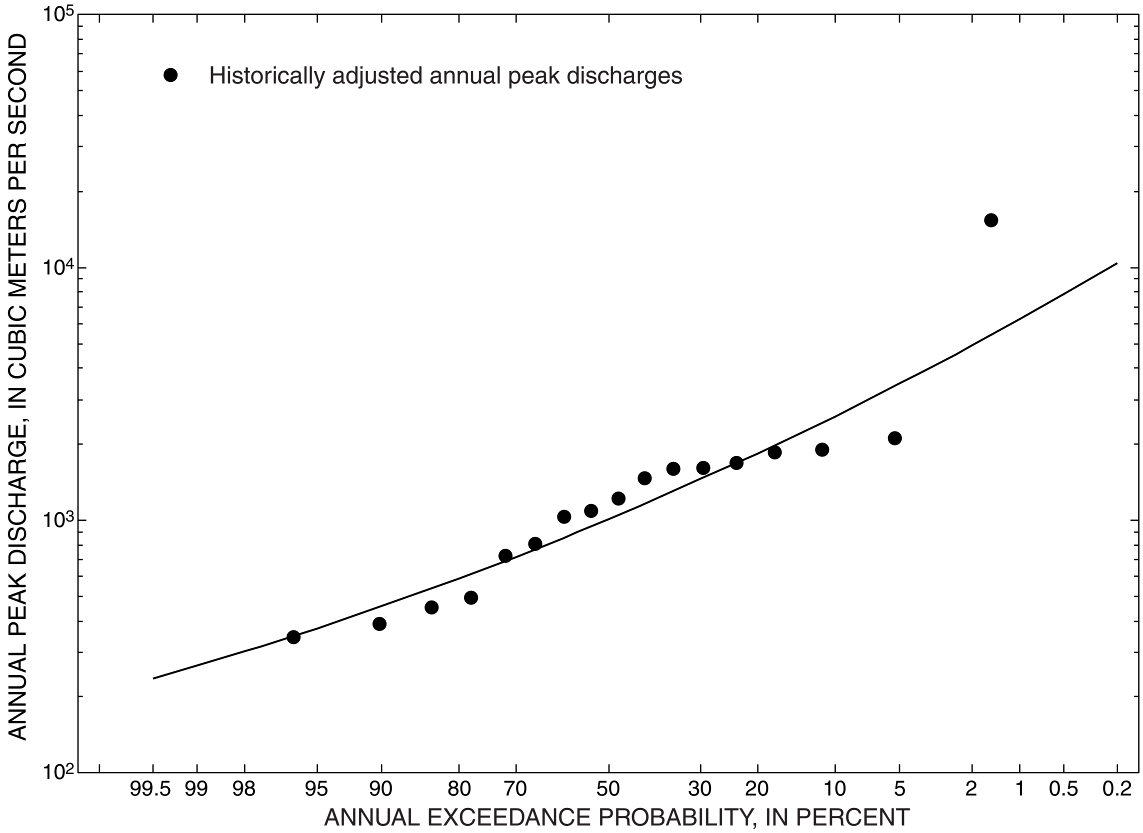

Figure 2. Exceedance probability of annual peak discharge for stream-gaging station Río Choluteca en Puente Choluteca, Honduras.

$$Q_{50} = 0.0788(DA)^{0.5664}(P)^{0.7693}\,, \qquad (1)$$

where

Q_{50} is the 50-year-flood discharge, in cubic meters per second (m^3/s),

DA is drainage area, in square kilometers (km^2), and

P is mean annual precipitation over the basin, in mm.

The standard error of estimate of equation 1, which is a measure of the scatter of data about the regression equation, is 0.260 log unit, or 65.6 percent. The standard error of prediction, which is a measure of how well the regression equation predicts the 50-year-flood discharge and includes the scatter of the data about the equation plus the error in the regression equation, equals 0.278 log unit, or 71.3 percent.

The drainage area upstream of the gaging station basin (6,942 km^2) and upstream of the reach of Río Choluteca included in the study area (7,080 km^2) were determined using a geographic information system (GIS) program to analyze a digital elevation model (DEM) with a 93-meter cell resolution from the National Imagery and Mapping Agency (Dave Stewart, USGS, written commun., 1999). The mean annual precipitation over the gaging-station basin was calculated to be 1,139 mm using a GIS program to analyze a digitized map of mean annual precipitation at a scale of 1:2,500,000 (Morales-Canales, 1997-1998, p. 15). The 50-year-flood discharge estimated from equation 1 for the gaging-station basin was 2,650 m^3/s.

The weighted average of the two estimated 50-year-flood discharges at the gage (4,913 m^3/s and 2,650 m^3/s) is 4,530 m^3/s. The 50-year-flood discharge for the study area reach of Río Choluteca (4,620 m^3/s) was estimated by multiplying the weighted-average discharge at the gage by the ratio of the drainage areas upstream from the two locations.

The 50-year-flood discharge for Río Iztoca at Choluteca was calculated from equation 1. A drainage area of 130 km^2 and a mean annual precipitation of 2,000 mm were determined for Río Iztoca using the same GIS coverages used to determine drainage area and mean annual precipitation for Río Choluteca. The resulting 50-year-flood discharge estimated for Río Iztoca is 430 m^3/s.

WATER-SURFACE PROFILES OF THE 50-YEAR FLOOD

Once a 50-year flood discharge has been estimated, a profile of water-surface elevations along the course of the river can be estimated for the 50-year flood with a step-backwater model, and later used to generate the flood-inundation maps. The U.S. Army Corps of Engineers HEC-RAS modeling system was used for step-backwater modeling. HEC-RAS is a one-dimensional, steady-flow model for computing water-surface profiles in open channels, through bridge openings, and over roads. The basic required inputs to the model are stream discharge, cross sections (geometry) of the river channels and floodplains perpendicular to the direction of flow, bridge geometry, Manning's roughness coefficients (*n* values) for each cross section, and boundary conditions (U.S. Army Corps of Engineers, 1998).

Cross-section geometry was obtained from a high-resolution DEM created from an airborne LIDAR survey. The LIDAR survey was conducted by personnel from the University of Texas. A fixed-wing aircraft with the LIDAR instrumentation and a precise global positioning system (GPS) flew over the study area on March 2-3, 2000. The relative accuracy of the LIDAR data was determined by comparing LIDAR elevations with GPS ground-surveyed elevations at numerous points on two easily detectable ground features in the Choluteca study area. The mean difference between the two sets of elevations at 862 points on one feature is -0.195 meter, and the standard deviation of the differences is 0.097 meter. The mean difference and standard deviation of the differences at 742 points on the other feature are -0.222 meter and 0.090 meter, respectively. The LIDAR data were filtered to remove vegetation while retaining the buildings to create a "bare earth" elevation representation of the floodplain. The LIDAR data were processed into a GIS (Arc/Info™) GRID raster coverage of elevations at a 1.5-meter cell resolution. The coverage was then processed into a triangular irregular network (TIN) GIS coverage. Cross sections of elevation data oriented across the floodplain perpendicular to the expected flow direction of the 50-year-flood discharge (figure 1) were obtained from the TIN using HEC-GeoRAS, a pre- and post-processing GIS program designed for HEC-RAS (U.S. Army Corps of Engineers, 2000). The underwater portions of the cross sections cannot be seen by the LIDAR system. However, because the LIDAR surveys were conducted during a period of extremely low flows, the underwater portions were assumed to be insignificant in comparison with the cross-sectional areas of flow during a 50-year flood; therefore, they were not included in the model.

A reconnaissance visit of the study area was made on October 25, 1999, to determine whether any bridges needed to be surveyed for inclusion in the HEC-RAS model. The only road crossing of Río Choluteca in the study reach is at the Pan American Highway crossing, which consists of two bridges, a suspension bridge across the main channel and a Bailey bridge across a large overflow channel north of the main channel. Two bridges cross Río Iztoca, one at the Pan American Highway about 3.6 kilometers upstream from the river's mouth and the other near the upstream end of the Río Iztoca study reach. The geometry for the Río Choluteca and Río Iztoca bridges was surveyed on March 14-15, 2000.

Most hydraulic calculations of flow in channels and overbank areas require an estimate of flow resistance, which is generally expressed as Manning's roughness coefficient, *n*. The effect that roughness coefficients have on water-surface profiles is that as the *n* value is increased, the resistance to flow increases also, which results in higher water-surface elevations. Roughness coefficients (Manning's *n*) for Río Choluteca and Río Iztoca were estimated from digital photographs taken during the field visit of the study area on October 25, 1999, from field observations and digital photographs taken during a field visit on March 14-15, 2000, and from computer displays of shaded-relief images of the LIDAR-derived DEM before the vegetation removal filter was applied. An *n* value of 0.035 was estimated for the main channel of Río Choluteca, and the *n* values estimated for the floodplain areas ranged from 0.040 to 0.065. An *n* value of 0.040 was estimated for the main channel of Río Iztoca, and the *n* values estimated for the floodplain areas ranged from 0.045 to 0.065.

Step-backwater computations require a water-surface elevation as a boundary condition at either the downstream end of the stream reach for flows in the subcritical flow regime or at the upstream end of the reach for flows in the supercritical flow regime. Initial HEC-RAS simulations indicated that the flow in Río Choluteca would be in the subcritical flow regime. Therefore, the boundary condition used was a water-surface elevation at cross section 0.104, the farthest downstream cross section of the Río Choluteca study reach in the step-backwater model. This elevation, 34.09 meters, was estimated by a slope-conveyance computation assuming an energy gradient of 0.001083, which was estimated to be equal to the slope of the main channel bed. The computed water-surface elevations at the first few cross sections upstream may differ from the true elevations if the estimated boundary condition elevation is incorrect. However, if the error in the estimated boundary condition is not large, the computed profile asymptotically approaches the true profile within a few cross sections.

The step-backwater model provided estimates of water-surface elevations at all cross sections for 50-year-flood discharges on Río Choluteca and Río Iztoca (tables 3-4 and figures 3-4). The computed flood elevations in the lower reach of Río Iztoca may be a little high because it is unlikely that 50-year floods would occur simultaneously on both Río Iztoca and Río Choluteca.

The calculated 50-year-flood water-surface elevation at the bridge across the overflow channel north of the Río Choluteca main channel at section 6.880 comes into contact with the bridge deck structure and causes some floodwaters to flow around the south end of the bridge. Consequently, this bridge is considered to be highly susceptible to failure from a 50-year flood.

Table 3. Estimated water-surface elevations for the 50-year flood on Río Choluteca at Choluteca, Honduras

[Peak flow for the 50-year flood is 4,620 cubic meters per second. **Cross-section stationing**: distance upstream from an arbitrary point near the model boundary; **Minimum channel elevation**, **Water-surface elevation**: elevations are referenced to the World Geodetic System Datum of 1984; **Abbreviations**: km, kilometers; m, meters; m/s, meters per second]

Cross-section stationing (km)	Minimum channel elevation (m)	Average velocity of flow (m/s)	Water-surface elevation (m)	Cross-section stationing (km)	Minimum channel elevation (m)	Average velocity of flow (m/s)	Water-surface elevation (m)
13.642	49.51	2.38	54.17	6.682	36.18	2.95	42.10
13.132	47.49	2.78	52.98	6.416	35.98	2.36	41.82
12.723	46.79	2.62	52.20	6.082	34.77	1.79	41.59
12.115	46.55	2.54	51.01	5.847	34.73	2.06	41.38
11.710	46.26	2.16	50.36	5.350	34.66	2.20	40.88
11.416	45.00	2.06	49.96	4.914	34.47	2.82	40.23
11.025	44.78	1.75	49.53	4.501	33.23	2.41	39.76
10.365	43.24	1.98	48.61	4.229	32.05	2.50	39.38
9.909	41.48	2.05	47.72	3.712	32.01	3.38	38.26
9.039	40.43	2.12	46.06	3.330	31.44	2.25	37.97
8.618	40.37	3.00	44.88	2.985	30.83	3.14	37.19
8.160	37.84	1.68	44.54	2.712	30.77	3.19	36.51
7.814	37.62	1.98	44.19	2.299	29.71	2.18	36.15
7.487	37.29	2.27	43.76	1.950	29.23	2.80	35.66
7.221	36.47	2.07	43.52	1.552	29.09	2.05	35.36
7.014	36.37	2.38	43.14	1.048	28.71	2.02	34.97
6.890	35.36	3.77	42.49	0.804	28.61	2.37	34.72
6.880 (bridges)				0.408	27.75	2.03	34.53
6.865	35.36	3.97	42.29	0.104	27.71	2.83	34.09

Table 4. Estimated water-surface elevations for the 50-year flood on Río Iztoca at Choluteca, Honduras

[Peak flow for the 50-year flood is 430 cubic meters per second. **Cross-section stationing**: distance upstream from confluence with Río Choluteca; **Minimum channel elevation**, **Water-surface elevation**: elevations are referenced to the World Geodetic System Datum of 1984; **Abbreviations**: km, kilometers; m, meters; m/s, meters per second]

Cross-section stationing (km)	Minimum channel elevation (m)	Average velocity of flow (m/s)	Water-surface elevation (m)
6.813	44.61	2.18	48.34
6.560	44.04	1.81	48.04
6.555 (bridge)			
6.540	44.04	1.83	48.01
6.314	43.71	2.24	47.42
5.839	42.30	2.07	46.45
5.416	41.95	2.47	45.48
4.584	38.63	1.69	43.51
3.821	36.91	1.85	42.41
3.640	36.75	1.51	42.31
3.630 (bridge)			
3.620	36.75	1.52	42.29
3.433	36.27	1.50	42.05
2.658	34.78	3.18	40.16
2.208	34.37	1.38	39.79
1.764	33.98	2.23	39.05
1.417	33.86	1.26	38.91
0.832	32.59	0.58	38.83
0.510	31.94	0.88	38.74

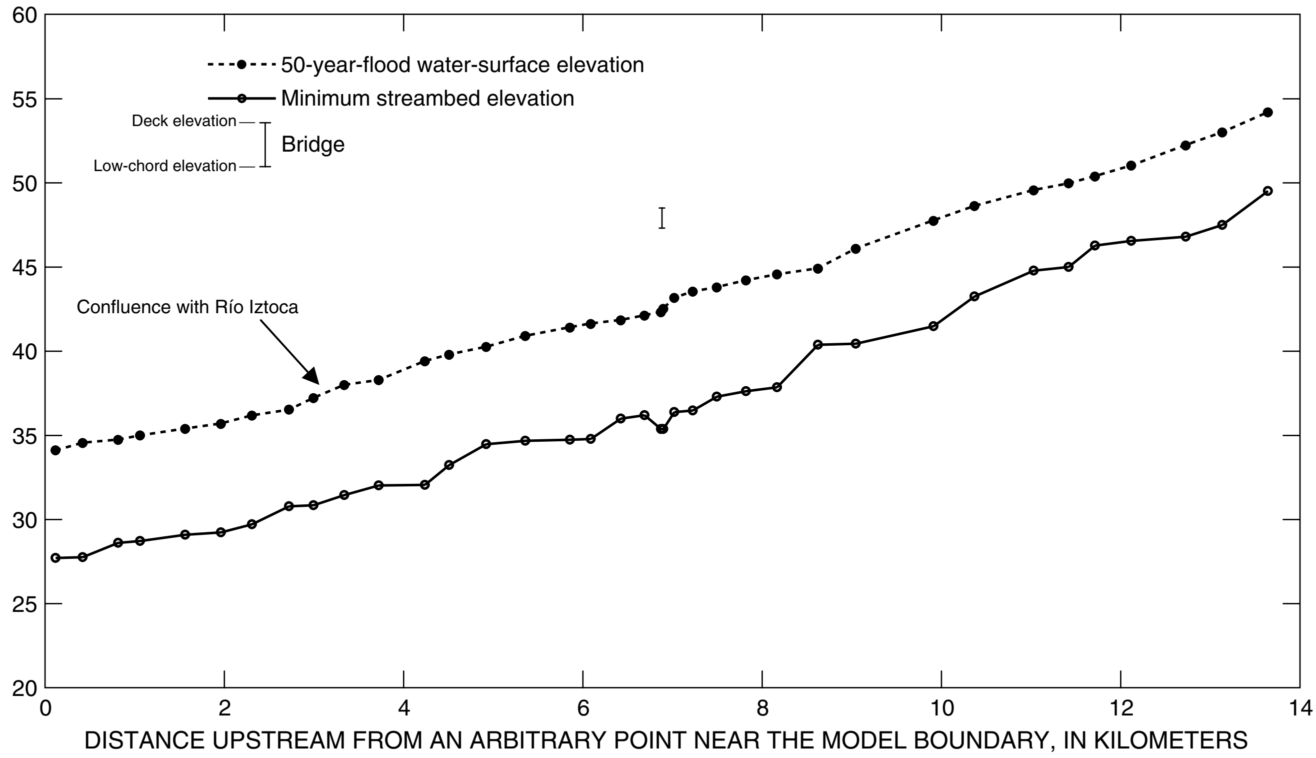

Figure 3. Water-surface profile, estimated using the step-backwater model HEC-RAS, for the 50-year flood on Río Choluteca at Choluteca, Honduras.

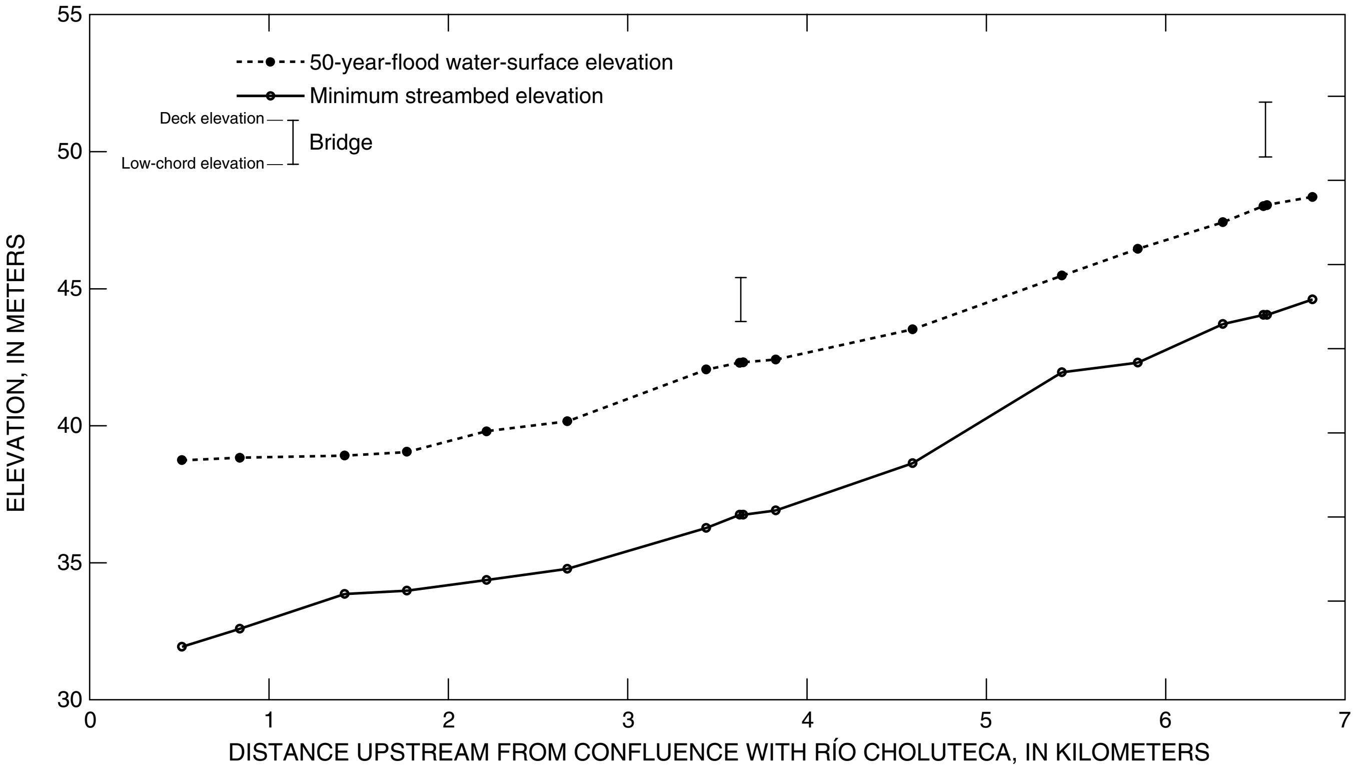

Figure 4. Water-surface profile, estimated using the step-backwater model HEC-RAS, for the 50-year flood on Río Iztoca at Choluteca, Honduras.

FIFTY-YEAR FLOOD-INUNDATION MAPS

The results from the step-backwater hydraulic model were processed by the computer program HEC-GeoRAS to create GIS coverages of the area and depth of inundation for the study area. The GIS coverage of area of inundation was created by intersecting the computed water-surface elevations with the topographic TIN that was produced from the LIDAR data. This coverage was then overlain on an existing 1:50,000 topographic digital raster graphics map (figure 1) produced by the U.S. National Imagery and Mapping Agency (Gary Fairgrieve, USGS, written commun., 1999). Depth of inundation at Choluteca for 50-year-floods on Río Choluteca and Río Iztoca (figure 5) was computed by subtracting the topographic TIN from a computed water-surface elevation TIN to produce a grid with a cell size of 3 meters.

The flood-hazard maps are intended to provide a basic tool for planning or for engineering projects in or near the Río Choluteca and Río Iztoca floodplains. This tool can reasonably separate high-hazard from low-hazard areas in the floodplains to minimize future flood losses. However, significant introduced or natural changes in main-channel or floodplain geometry or location can affect the area and depth of inundation. Also, encroachment into the floodplains with structures or fill will reduce flood-carrying capacity and thereby increase the potential height of floodwaters, and may also increase the area of inundation.

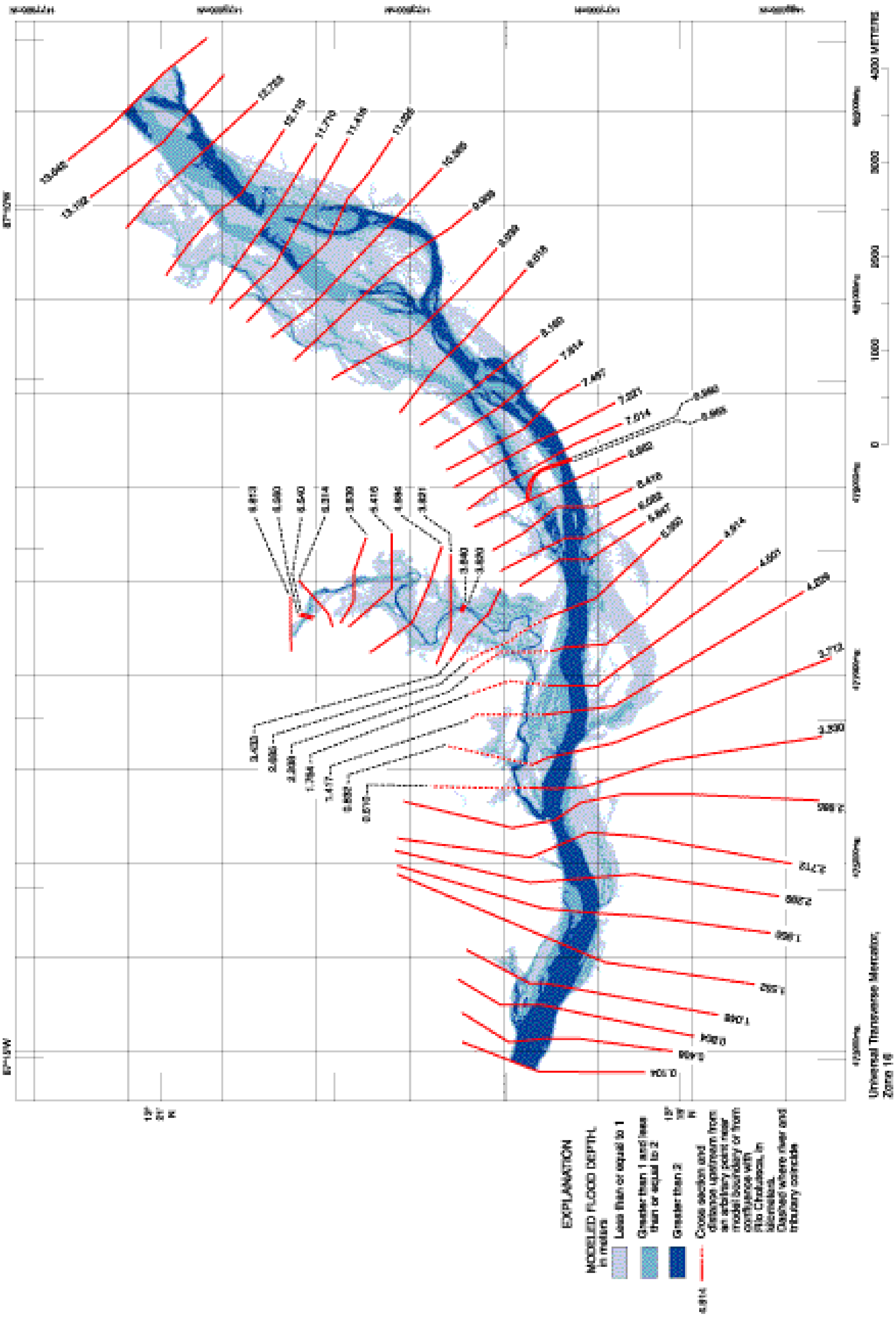

Figure 5. Depth of inundation of the 50-year flood and location of cross sections on Río Choluteca and Río Iztoca at Choluteca, Honduras.

DATA AVAILABILITY

GIS coverages of flood inundation and flood depths shown on the maps in figures 1 and 5 are available in the Municipal GIS project, a concurrent USAID-sponsored USGS project that will integrate maps, orthorectified aerial photography, and other available natural resource data for a particular municipality into a common geographic database. The GIS project, which is located on a computer in the Choluteca municipality office, allows users to view the GIS coverages in much more detail than shown on figures 1 and 5. The GIS project will also allow users to overlay other GIS coverages over the inundation and flood-depth boundaries to further facilitate planning and engineering. Additional information about the Municipal GIS project is available on the Internet at the GIS Products Web page (http://mitchnts1.cr.usgs.gov/projects/gis.html), a part of the USGS Hurricane Mitch Program Web site.

The GIS coverages and the HEC-RAS model files for this study are available on the Internet at the Flood Hazard Mapping Web page (http://mitchnts1.cr.usgs.gov/projects/floodhazard.html), which is also a part of the USGS Hurricane Mitch Program Web site.

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